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## Eagle RTS: A Design of A Regional Transport

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### Introduction

The Eagle RTS (Regional Transport System) is a 66-passenger aircraft designed to satisfy the need for accessible and economical regional travel. The first design objective for the Eagle RTS is safety. Safety results primarily from avoidance of the hub airport air traffic, implementation of anti-stall characteristics by tailoring the canard, and proper positioning of the engines for blade shedding. To provide the most economical aircraft, the Eagle RTS will use existing technology to lower production and maintenance costs by decreasing the amount of new training required.

In selecting the propulsion system, the effects on the environment were a main consideration. Two advantages of turbo-prop engines are the high fuel efficiency and low noise levels produced by this type of engine. This ensures the aircraft's usage during times of rising fuel costs and growing aircraft noise restrictions.

The design of the Eagle RTS is for spoke-to-spoke transportation. It must be capable of landing on shorter runways and have speeds comparable to that of the larger aircraft to make its service beneficial to the airlines. With the use of turbo-prop engines and high lift devices, the Eagle RTS is highly adaptable to regional airports. The design topics discussed include: aerodynamics, stability, structures and materials, propulsion, and cost.

### Aerodynamics

The fuselage of the Eagle RTS resembles an elongated "teardrop" shape with pusher-prop engines located behind the swept-back wings. This configuration will allow for minimum body drag while allowing for maximum flexibility in designing the interior arrangement. Figure 2 provides a three-view of the Eagle RTS.

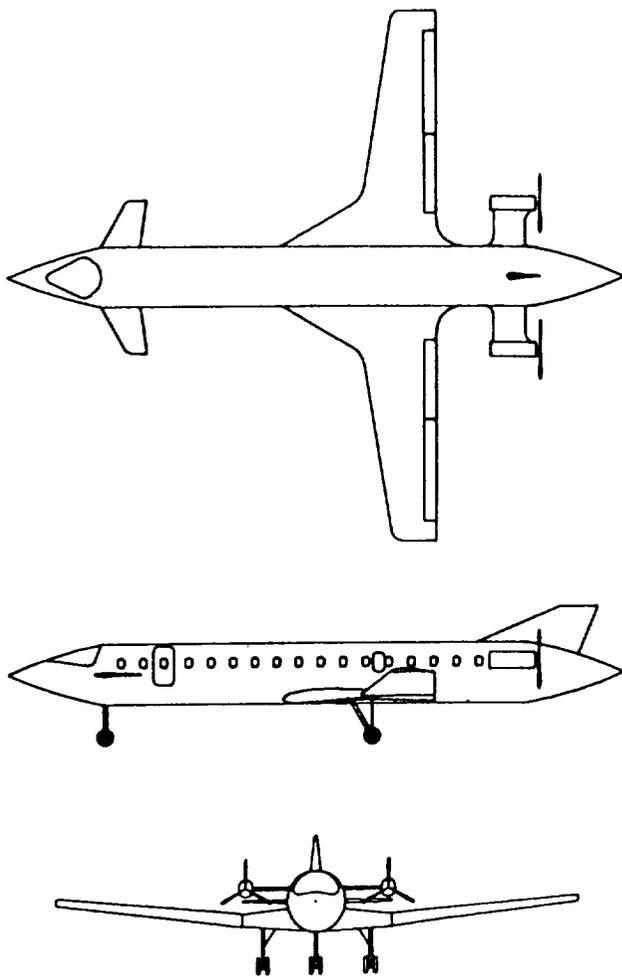


Fig. 2 Three-View of of the Eagle RTS

The airfoil selected for the wing is the NACA 632-615 series airfoil. This airfoil was selected because it has the most efficient cruise characteristics and a high stall angle of attack.<sup>1</sup> The choice of airfoil was also influenced by Daniel P. Raymer's recommendation of a wing thickness ratio for twin turbo-prop aircraft of 0.14.<sup>2</sup>

The Eagle RTS uses a compound wing design with sweep angles of 9° and 60° and wing loading of 70 lb per sq ft. These angles were chosen to provide a wing area which produced a maximum lift coefficient and a minimum wing loading while providing for large fuel

tanks.

The drag polar was calculated using Roskam's Methods for Estimating Drag Polars of Subsonic Airplanes,<sup>3</sup> which shows the drag coefficient to be:

$$C_D = 0.0615 + 0.032 C_L^2.$$

The Eagle RTS will employ the use of a canard to prevent stall characteristics such as spins and uncontrolled rolls. The canard airfoil selected for the Eagle RTS is the NACA 0009 series. The canard will cruise at an angle of attack of 2° while stalling at an angle of attack of 9° ± 1°. Because the canard will stall at 9° the main wing will never reach its stall angle of attack of 12°. The canard was also employed to eliminate the negative lift normally generated by the tail.

One disadvantage of a canard is the effect of trailing vortices on the main wing aerodynamics and the engine efficiency. To minimize these effects, Raymer's approach was used, where both the main wing and engines are placed as far aft and above the canard as possible.

The aspect ratio for the Eagle RTS is important in determining the induced drag and efficiency of the aircraft. The aspect ratio for the Eagle RTS was found to be 6.5, corresponding to a induced drag of 0.032 and an efficiency factor of 0.775. According to Richard S. Shevell, an efficient aircraft operates between an Oswald's efficiency factor of 0.75 and 0.9.<sup>4</sup>

### Performance

Two important factors in aircraft performance are rate-of-climb and range. The rate-of-climb at cruise velocity and cruise altitude of 25,000 ft with full passenger and fuel load was found to be 928 ft/min. In the initial analysis it was estimated that the range would be 1000 nmi. To find the maximum range, we use a maximum lift to drag ratio. Using an efficiency of 0.8 and a TSFC of 0.547 lb/hr-HP the range was calculated to be 836 nmi. Although below what was specified at the beginning of the design process, the range of this airplane was deemed to be adequate.

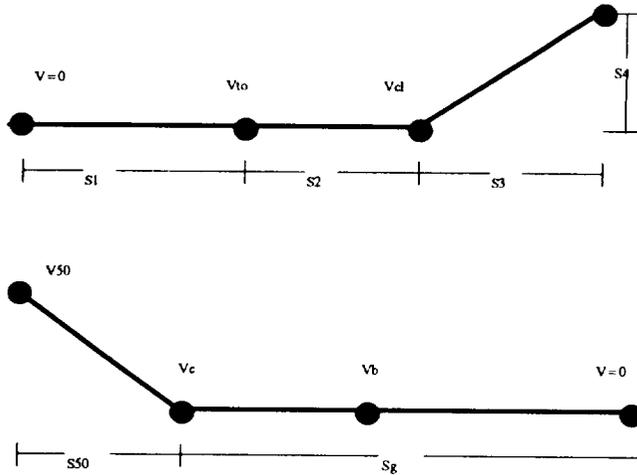


Fig. 3. Takeoff and landing breakdown

The total takeoff distance required is 4700 ft. Figure 3 gives a diagram of takeoff and landing roll distances, and Table 3 gives the takeoff and landing distances for the Eagle RTS.

Table 3 Takeoff and landing information

<b>Takeoff Parameters:</b>		
$V_{TO} = 186.05$ ft/s	$V_{CL} = 202.96$	
$S_1 = 3563.64$ ft	$S_2 = 762.82$ ft	$S_3 = 370.04$ ft
$STO = 4696.4952$ ft		
<b>Landing Parameters:</b>		
$V_{50} = 219.87$ ft/s	$V_C = 194.5$ ft/s	$V_B = 155.6$ ft/s
$S_{50} = 1964.44$ ft	$S_G = 1719.623$ ft	
$STL = 3684.063$ ft		
$STL_{commercial} = 6140.0$ ft		

The total landing distance is 3700 ft, roughly two-thirds the takeoff distance. FAR requirements for a commercial aircraft show the landing distance to be 6100 ft. With the addition of ground spoilers this landing distance will decrease.

**Stability Analysis**

The stability analysis of the Eagle RTS includes a

comparison of pitching moment versus angle of attack, neutral point location, and the stability margin. This is normally described by the moment coefficient,  $C_m$ . In order to find this value of  $C_m$  and subsequently the variation of it with angle of attack, the neutral point or static margin must be found.

Table 4 C.G. locations for various loading conditions

Configuration	C.G. Location (ft.)*	Static Margin (ft.)
Full passengers and bags, full fuel	50.7509	12.390
3/4 passengers and bags, 1/2 fuel	51.5363	11.604
No pass., no bags, no fuel (empty landing)	56.8650	6.280
Avg. passenger weight	170 lb	
Avg. baggage weight	3130 lb	
Total passenger weight	11,220 lb	
Avg. fuel weight	14,280 lb	

\* Measured from the nose of the aircraft

Table 4 shows the component weights and center of gravity locations for various loading conditions. Due to the changing configurations of passenger and baggage loadings, the neutral point of the aircraft should be found first. In this case, the neutral point was found to be 15.892 ft forward from the trailing edge of the wings, or 58.1 ft aft of the nose. The aerodynamic center was found to lie 63.14 ft from the nose, while the center of gravity is located 50.7509 ft aft from the nose. All are for the fully loaded aircraft configuration.

Finally, the variation of  $C_m$  with angle of attack for various deflections of the canard may be found. The significance of the canard surface in this design is its freedom from propulsive interference, which allows it to better trim the large moment produced by high lifting

devices. An unfavorable aspect of the canard is its destabilizing effect on the airplane. However, this can be counteracted by proper positioning of the center of gravity.<sup>5</sup>

In the commercial aviation market, passenger ride comfort is a prime consideration in customer satisfaction. This gives rise to dynamic stability analysis, which plays a major role in aircraft handling and ease of flying. The phugoid or long period mode is characterized by changes in pitch, altitude and velocity. In this analysis, the period of the phugoid motion was found to be 6.91 minutes and the time to half amplitude of 103 minutes. The short-period was determined to be 0.147 minutes and a time to half amplitude of 2.42 minutes. Although this aircraft is balanced and stable, the automatic stabilization computer must be used to augment both the short and long period frequencies.<sup>5</sup>

### Structures and Materials

The exterior dimensions of any commercial aircraft are based primarily on the number of passengers the aircraft will carry. The number of passengers is of prime importance since it dictates the cabin dimensions, airline profit and feasibility, and future applications of the aircraft. Based on these factors and market influences, the Eagle RTS will accommodate 66 passengers with a four-abreast seating configuration.

The mission profile for the Eagle RTS included eight phases: start-up, taxi, takeoff, climb, cruise, loiter, descent, landing, and shutdown. A preliminary weight estimation of the Eagle RTS then determined the gross takeoff weight to be approximately 70,000 lbs. Using the fraction method of component weights by referencing similar aircraft, the weight of the major component groups is given in Table 5.

The next phase of the design is to determine construction materials for construct the Eagle RTS. Material selection is based on the maximum loads applied to the aircraft during flight. The wing loading was determined to be 100 lb/ft<sup>2</sup>, with a 1.5 safety factor for normal cruise conditions.

Table 5 Component weight breakdown

Component	Weight (lbs)
Fixed equipment	11,014.0
Fuselage	8204.0
Wing mass	8540.0
Landing gear mass	3190.0
Empennage mass (including tail)	1899.0
Engine mass	6304.0
Nacelles mass	1823.0
<b>Total Component Weight</b>	<b>40,974.0</b>

The materials used for the construction of the Eagle RTS will be an integration of aluminum alloys and composites. The skin and stringers of the upper surface will be constructed of an aluminum alloy, 7075 (Al-Zn), which has high tensile stresses allowances. For the lower surface of the wing, the alloy 2024 (Al-Cu) will be used. Based on the values determined from the MSC/NASTRAN results, the materials used are sufficient to withstand the loads applied during flight.

As previously stated, aluminum alloys will be the dominant material used on the Eagle RTS. This is mainly because of their strength characteristics, high corrosion resistance, availability, low cost, and acceptability. Another alloy used on the Eagle RTS is aluminum-lithium, which demonstrates very high strength characteristics and low weight. However this material will be in limited use since the raw material cost is greater than that of standard alloys.

In order for the Eagle RTS to operate at its maximum efficiency, the weight of the aircraft must be minimized. Composite materials will be used in limited areas to maximize efficiency and minimize cost. Composites demonstrate a weight savings of approximately 25% over metals, can be tooled to any shape while maintaining their physical properties, and give a smoother surface than metals. These materials will adjust the empty weight of the Eagle RTS to 40,415 lbs. The composites will be used in the leading and trailing edges of the wing, the inboard and outboard flaps, rudders, elevators, and landing gear doors. A final estimate of the final gross take-off weight

is calculated to be 69,045 lbs.

### Propulsion

The propulsion system for the Eagle RTS was selected to allow cruise at 25,000 feet at a speed of 260 knots (Mach 0.4). Viable options at this speed were turboprop and turbofan type engines, but fuel savings of 25% for the turboprops resulted in their selection.

Once the engine type was selected for the Eagle RTS, the thrust required, engine size, and propeller specifications were determined. In level, unaccelerated flight the thrust required is equal to the drag on the aircraft. The thrust required at the cruise altitude of 25,000 feet was determined to be 6300 pounds. This is 3150 hp per engine for a twin turboprop configuration. The highest rated engine currently on the market is the PW 126 produced by Pratt & Whitney, Canada (P&WC). It is cruise-rated at 2192 effective horsepower (ehp) at 1200 rpm. However, P&WC is currently testing engines with effective horsepower in the range of 3000 ehp.<sup>4</sup>

The dimensions and weight of the engines for the Eagle RTS can be calculated using the scaling equations.<sup>2</sup> Using the PW 126 as a baseline engine, the Eagle RTS engine is calculated to have a length of 97.1 inches, a width of 31.2 inches, a height of 37.2 inches, and a weight of 1675.6 pounds.

When noise is a consideration, the helical tip speed of the propeller blades should be kept at or below 700 feet per second. At a rotational rate of 1200 rpm and a cruise velocity of 260 knots, the propeller disk diameter is calculated to be 104 inches.

Engine placement is crucial to aircraft safety. The propeller blades require a minimum clearance of 9 in. For that clearance and the instances of blade shedding, vortices shedding from the canard, and noise considerations, the engines have been placed on pylons on the aft section of the fuselage, mounted in a pusher configuration.

### Cost Analysis

The direct operating costs (DOC) of the Eagle RTS are divided into three sections: fuel, crew salaries, and

maintenance. The fuel cost was calculated by determining the amount of fuel burned per year. Assuming an average of 4000 flight hours per year, the fuel cost is \$1.5 million per 1000 flight hours. The crew salaries are estimated to be \$209,000 of the DOC. The maintenance costs per year can be estimated by determining the maintenance hours required per flight hour. The maintenance cost per year was calculated to be \$30,000. The majority of the maintenance costs are due to the type of engine selected for the Eagle RTS. The remaining cost of the DOC is the depreciation and insurance value. Therefore the direct operating cost of the aircraft per 1000 flight hours was determined to be \$1.04 million.

The calculation of the total cost of the Eagle RTS is based on calculations from Raymer.<sup>2</sup> The selling price (in 1992 constant dollars) for the Eagle RTS, including an investment factor, is set at \$10.2 million for 500 aircraft, with the total cost of the Eagle RTS project estimated to be \$5.1 billion. Also, each aircraft will have an expected operational life of 60,000 flight hours or approximately 15 years. At this price and operational life, the Eagle RTS will surely be competitive with the other aircraft in the regional commercial market.

### Summary And Conclusions

The Eagle RTS was developed to meet a specific gap in the commercial aircraft industry. It was designed to carry passengers between metropolitan areas while avoiding the congested hub airports. The aircraft is designed to maximize performance while minimizing operational costs.

Several interesting conclusions were reached during the final phases of the design. Only time and research will provide an answer to the problem of canard tip vortex shedding on the placement of the engines, engine performance, and the aerodynamic effects on lifting surfaces. In terms of the weight of the aircraft, the values represent preliminary design estimates only, since time limitations and constant adjustments in the configuration were required. On the performance side, the range came out significantly better than our initial assessment, and the endurance is competitive with the specified needs. Also, the aircraft computer system will calculate the optimal engine fuel flow to maintain peak engine efficiency. Since

the aircraft aerodynamics were developed assuming non-laminar flow, proper cleaning and maintenance will further minimize fuel consumption and further lower the operational costs of the aircraft. In the final analysis of the design, the Eagle RTS is well researched and will fill a void that exists in today's regional transport market.

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